Fiber-Optic Amplifiers

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Introduction

SEL manufactures many devices that communicate using fiber-optic technology. The optical distances these devices operate over vary based on the type of optical components used. SEL manufactures products that operate over a distance of a few hundred meters to more than 100 kilometers.

This application note is intended to address systems with fiber-optic paths of more than 100 kilometers and fiber-optic products operating in the 1550-nanometer light range.

Problem

Occasionally, fiber-optic cable installations span distances greater than the maximum range specified for the SEL product. Additionally, the cable route may not allow for the use of repeater sites, or the best location for a repeater site may be too far outside SEL product's reach to be applied.

SEL Solution

When applying an SEL fiber-optic product in an application with a fiber span greater than the maximum optical cable length listed in the product specification, the addition of an optical amplifier is one possible solution. SEL recommends the use of an erbium-doped fiber amplifier (EDFA) for these applications. This device amplifies light in the 1529- to 1562-nanometer range. An EDFA is not data-rate dependent and can be applied to the following SEL products with 1550-nanometer fiber options as applicable:

- SEL-2831 Single-Mode Fiber-Optic Transceivers
- SEL-311L Line Current Differential Protection and Automation System
- SEL-411L Advanced Line Differential Protection, Automation, and Control System
- SEL ICON® Integrated Communications Optical Network

Fiber System Gain Calculations

SEL uses conservative figures to calculate the distances each fiber-optic product can reliably communicate over. When applying an SEL product at the stated maximum distance and beyond, always start with the system gain capabilities of the product. The following is the simple formula to calculate system gain:

System gain = TX power – RX sensitivity

The following is an example for the SEL-411L with 1550-nanometer optics:

–18 dB TX power – (–58 dB RX sensitivity) = 40 dB system gain

The system gain is the maximum level to which the transmitted signal can be attenuated as it passes through the fiber system. Figure 1 depicts the various system components that contribute to attenuation in a system.

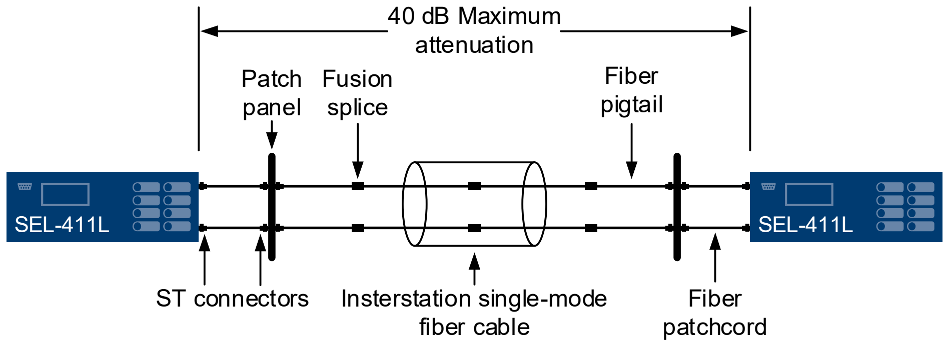


Figure 1 Fiber System Loss Budget Example

The system loss budget calculated in Table 1 demonstrates the maximum calculated fiber distance that the SEL-411L can operate over. The values used are typical for low-loss fiber cable; calculations should be performed using actual cable attenuation (dB/km) figures for every system that will operate close to the specified maximum limit for the product being used. The fiber cable installation should also be measured when the installation is complete to verify the calculated versus measured attenuation performance.

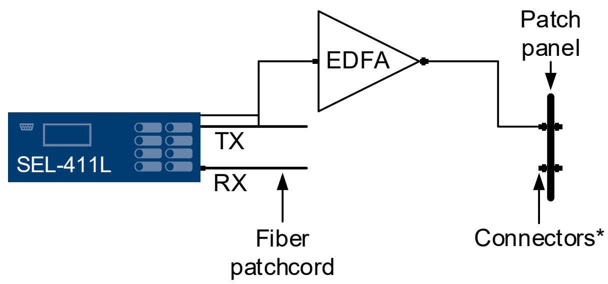
Table 1 Fiber-Optic System Loss Calculation Example

Typical Attenuation Value	Loss Calculation	System Loss Budget
Cable attenuation = km • 0.22 dB/km	170 • 0.22 dB/km	37.4 dB
Splice loss = 0.05 dB per splice, every 6 km	30 • 0.05 dB	1.5 dB
Fiber connector loss – 0.3 dB per	3 • 0.3 dB	0.9 dB
	Total system loss	39.80 dB

Note: System gain – total system loss = system margin. In the examples in this application note, we show very low margins. SEL recommends 3 dB of margin on any fiber system.

Application of an Erbium-Doped Fiber Amplifier

An EDFA can be used to boost the transmitted optical signal level. This amplifier can operate in several modes. This application note is specific to the booster amplifier operating mode. In this mode, the amplifier is collocated with the transmitting optical device as shown in Figure 2.



* Connector types may vary based on amplifier connector options

Figure 2 Application Example of a Booster Amplifier

A typical booster amplifier will add 14 dB or more to the transmitted optical signal. Care should be taken not to exceed the maximum input level of the amplifier (typically 0 dBm). This amplification can be added directly to the calculated gain of the system. For example, the SEL-411L system gain of 40 dB previously calculated will increase to 54 dB when an amplifier is used, as shown in Figure 2. Table 2 demonstrates that with 54 dB of system gain, distances of up to 230 kilometers are achievable. Note that to achieve the 230-kilometer distance, the attenuation values of Table 2 must first be achieved.

The following is an example of the system gain for the SEL-411L with 1550-nanometer optics:

–18 dB TX power – (–58 dB RX sensitivity) = 40 dB system gain

40 dB system gain + 14 dB amplifier gain = 54 dB system gain

Table 2 Fiber-Optic System Loss Calculation Example With an EDFA

Typical Attenuation Value	Loss Calculation	System Loss Budget
Cable attenuation = km • 0.22 dB/km	230 km • 0.22 dB/km	50.6 dB
Splice loss = 0.05 dB per splice, every 6 km	40 • 0.05 dB	2 dB
Fiber connector loss = 0.3 dB per connector	3 • 0.3 dB	0.9 dB
System gain with amplifier	Total	53.50 dB

IPG Photonics’ EAR Series amplifiers are suitable for these applications. These amplifiers have had good results on several projects with links up to 245 km during tests using the IPG Photonics EAR-30-C3-1U with 30 MW output.

Signal Dispersion at Higher Bit Rates

The amplifier example shown in Figure 2 can be applied to the SEL-311L, SEL-411L, and SEL-2831 products. These products communicate at relatively low bit rates of 64 kbps or less. The SEL ICON™ interface operates at a much higher rate of OC-48 (2.44 Gbps). At this high bit rate, an additional concern is the effect of chromatic dispersion.

Chromatic dispersion is the broadening of the signal pulse over distance. The combination of the 2.44 Gbps bit rate and the long fiber span (>200 kilometers) brings dispersion into play for this application. Due to the effect of dispersion on the 2.44 Gbps signal, booster amplifiers may require additional dispersion compensation. Refer to the amplifier’s documentation or manufacturer if this is a concern. ICON nodes can be used as repeaters if intermediate sites with power are available.

CLOSING NOTE

This application note is intended to provide an alternate solution to repeater site equipment for long fiber cable installations. It is necessary to work with the cable provider in the selection of the right fiber for the application. The cable manufacturer should also provide guidance regarding dispersion characteristics for the fiber cable selected.